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Estimating the Life of Asphalt Overlays

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Abstract:
Asphalt concrete overlays of flexible pavements are the most common pavement rehabilitation treatment in Ontario. This report describes the development of mathematical models for the performance prediction of these overlays. The modelling approach was based on a statistical evaluation of observed overlay performance and uses readily available data. Its objective was to develop performance prediction models which would fit the existing pavement management system and could be used for life-cycle economic analyses.

The length of overlay life-cycle, for a predetermined terminal serviceability, was estimated as a function of overlay thickness, traffic (number of equivalent single axles), maintenance patching, and the life-cycle length of the initial pavement. The latter variable was included in the model to capture the influence of local field conditions and to characterize the strength of the underlying support structure. Maintenance patching was included to quantify the effect of pavement maintenance on overlay performance.

The proposed models are preliminary and should be updated when more data becomes available. The modelling apprach developed in this report may be used for performance prediction of other pavement rehabilitation treatments.

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1/ INTRODUCTION

One of the basic building blocks of any pavement management system is the prediction of pavement performance. The process of pavement performance prediction, within the pavement management framework, encompasses [1]:

a) when a pavement preservation action will be required,
b) what this preservation action should be, and
c) what would be the consequences (benefits) of this action.

This report addresses the last item, the consequences of pavement preservation actions for the most common rehabilitation treatment -- asphalt concrete overlays over asphalt concrete pavements.

The objective was to develop models which would permit estimation of the immediate effect of an overlay on pavement serviceability and to determine and quantify factors governing the relationship between overlay strength, or thickness, and its life-cycle period.

The selection of prediction modelling techniques was strongly influenced by data availability and by the type of results required in the context of the Ministry's pavement management system [2]. A determined effort has been made to capitalize fully on the advantages of a pavement management information data bank, particularly on the availability of historical pavement performance data.

2/ DATA COLLECTION

The objective of the data collection process was to obtain, for a number of pavement sections, a complete record of pavement serviceability data spanning its initial life-cycle following a new construction, reconstruction or a major rehabilitation, as well as its subsequent life-cycle following an overlay. The two pavement performance life-cycles are shown in Figure 1. In addition to the historical pavement serviceability data, other data deemed to influence overlay life, such as traffic data, overlay thickness, length of the initial pavement life [3], and the pavement condition before resurfacing in terms of roughness and various pavement distresses, were also collected.

The estimated lives of the initial and overlaid pavements were not actual lives, but the ages of the pavements when serviceability reaches a Pavement Condition Rating of 55. Rehabilitation is mostly done anywhere between 40 and 60.

2.1/ Data Sources

Because the pavement information data bank was not yet fully functional, additional data had to be obtained from a variety of sources including Pavement Performance Records [4], contract drawings and traffic files. The requirement of historical pavement serviceability data for two pavement life-cycles, covering up to 40 years, posed considerable data collection problems.

Due to incomplete records, and rather demanding data requirements, it was not possible to obtain the required data for pavement sections selected randomly. Rather, in assembling the data set used for modelling, all readily available observations were used. Altogether, data for more than 50 pavement sections, ranging in length from 5.0 to 26.7 km were obtained.

Detailed data on all observation sections are summarized in Appendix A. The first 50 observation sections in the Appendix were used for the development of prediction models; the last 6 sections were used for their verification.

2.2/ Data Description

Since the objectives of the modelling were broad, and in view of uncertainties as to which variables may significantly influence overlay performance, each pavement observation section was characterized by more than 30 variables or factors. These variables were grouped into the following seven categories:

a) Section identification
b) Traffic characteristics
c) Environmental characteristics
d) Initial pavement structure and its maintenance
e) Initial pavement performance
f) Overlay structure and its maintenance
g) Overlay performance

The principal characteristic variables collected for all pavement observation sections are described in the following. Additional variable definitions and detailed data are given in Appendix A.

a) Section Identification

DIST - MTC District number. 11 of the 18 MTC districts are represented.

LENGTH - Section length. The average section length was 13.5 km.

b) Traffic Characteristics

AADT83 - 1983 Annual Average Daily Traffic volume. The volume ranged from 1000 to 8000 vehicles with an average of 3700 vehicles.

TRUCK - Percentage of trucks in 1983 traffic flow. The truck percentage ranged from 4 to 24%, the average was 14%.

GRA2 - Percentage growth in traffic volumes between 1973 and 1983. The average growth was 8%.

Other traffic data included truck factor (number of equivalent axles per truck) and various historical AADT volumes.

c) Environmental Characteristics

FREEZE - Freezing index [5], ranging from 420 to 2040 degree days Celsius. Section location, characterized by one of the 18 MTC districts, can also be considered as an environmental characteristic.

d) Initial Pavement Structure and its Maintenance

The initial pavement structure was usually a new construction or a reconstruction. In four cases, the initial pavement structure was an overlay. The maintenance of the initial pavement structure was recorded only in terms of patching.

GRANA - Average thickness of granular base expressed as granular base course (Granular A) equivalent thickness [6]. The thickness ranged from 125 to 510 mm, the average was 300 mm.

BEFAC - Total average thickness of asphalt concrete. The range was from 50 to 200 mm, the average was 100 mm.

PATCH - Extent of machine (full-width) patching before rehabilitation.

e) Initial Pavement Performance

In general, pavement performance was characterized by a performance curve and by the results of a detailed pavement distress survey conducted just before overlay placement.

BEFCON - Pavement Condition Rating (PCR) at the beginning of the initial cycle. This is a measure of overall pavement serviceability on a scale 0 to 100 [4]. Newly constructed pavements generally have a PCR of 95 and rehabilitation usually occurs before the rating reaches 50. A typical plot of historical PCR data is shown in Figure 1.

BEF55 - Life span of the initial pavement defined as the number of years required for the initial pavement structure to reach a terminal serviceability. The terminal serviceability was arbitrarily set at a PCR level equal to 55 (Figure 1). This "normalized" definition of the life-cycle length was adopted in order to define pavement life span solely in terms of pavement performance rather than in terms of actual construction timing. If the rehabilitation took place before the pavement reached the 55 level, its BEF55 was obtained by extrapolating the performance curve. The average BEF55 was 13.1 years.

RCR - Ride Comfort Rating just before rehabilitation. The average RCR was 5.1. This and the subsequently described variables were not normalized.

DM - Distress Manifestations index [4] just before overlay placement. DM was calculated as the sum of 25 individual pavement distresses, characterized by their severity and extent, and weighted according to their contribution to the PCR. Pavements without distresses have DM equal to 0, pavements with many distresses, such as surface deformation and cracking, may have DM exceeding 100.

ALLIG - Total alligator cracking just before overlay placement. ALLIG is a portion of DM summarizing all types of alligator cracking.

f) Overlay Structure and its Maintenance

THOV - Total overlay thickness in mm including surface and binder courses but not including padding. The overlay thickness ranged from 40 mm to 175 mm, the average was 70 mm.

PATCH - Extent of patching before rehabilitation. Crack sealing was also recorded but virtually all patched overlays had also undergone crack sealing.

g) Overlay Performance

The overlay performance was characterized by the performance curve in terms of PCR. The following parameters of the performance curve were collected:

NPCR - PCR immediately after overlay.

AFT55 - Life span of the overlay cycle defined as the number of years before the overlay reached the PCR level of 55 (Figure 1). The reasons for this normalized definition of overlay life were the same as those for BEF55. The average overlay life span was 14.8 years, 1.7 years longer than the average life span of the initial pavement structure.

ΔPCR5 - Change in PCR during the first 5 years following overlay placement.

3/ DEVELOPMENT OF PREDICTION MODELS

The result of the data collection phase was a detailed record of pavement performance and pavement structural changes, including major maintenance activities, covering a period of two pavement life-cycles. This record was available for 20 pavement sections; the record covering a period of 1 1/2 pavement cycles was available for additional 30 sections. These records were used to predict overlay performance in terms of the following performance characteristics:

1. immediate increase in PCR after overlay placement,
2. length of overlay life-cycle, and
3. PCR change during 5 years after overlay placement.

3.1/ Immediate Increase in PCR Following Overlay Placement

Based on 50 observations, the average increase of PCR after overlay placement, or the average PCR jump, was 53 PCR units. The range was from 32 to 66 PCR units. A plot of the PCR jump versus overlay thickness shown in Figure 2 indicates that there was no correlation between these two variables.

The only factor with a statistically significant influence on the PCR jump was the PCR level (or also RCR level) before the overlay. The PCR jump increased as the PCR level before the overlay decreased. This reflects the fact that the PCR can theoretically reach a level of only 100 regardless of overlay thickness. Thus, pavements with low PCR level before the overlay have greater opportunity to realize large PCR jumps. Furthermore, the PCR is subjectively assigned and PCR raters may be influenced by the halo effect [7] and be inclined to rate all newly overlaid pavements near the top of the PCR scale. At any rate, no useful prediction model for the PCR jump could be constructed.

3.2/ Length of Overlay Life-Cycle

The length of time an overlay will last before reaching terminal serviceability is a basic performance characteristic necessary for any life-cycle economic evaluation. The concept of linkage between the length of overlay life-cycle and the terminal serviceability is very important. In this analysis, the terminal serviceability was set at PCR equal to 55.

The prediction of the overlay life-cycle length required pavement performance data for two pavement life-cycles. 20 observation sections satisfied this condition.

3.2.1/ Model Development

Statistically, the modelling approach was based on linear regression techniques. The selection of independent variables was based on past experience which suggests that the prediction of overlay life depends on the following factors:

- overlay strength (i.e., overlay thickness, quality of overlay materials and quality of their placement)
- strength and condition of pavement structure being overlaid
- maintenance effort, and
- traffic and environment exposures.

For many of these factors, the data base contained several variables which could be used for their description and quantification. However, in order to avoid having too many parameters in the model (overparametrization) and to obtain a simple predictive model fitting the pavement management framework, a conscious effort was made to select only one variable to characterize any one of the above factors.

A number of different models were constructed and evaluated. The evaluation was based on rational formulation and behaviour of the model and on its statistical parameters. The following model was selected for the prediction of the overlay life-cycle:

$$AFT55 = 1.32 \cdot BEF55^{0.33} \cdot THOV^{0.47} \cdot ESAL^{-0.097} \cdot 1.14^{PATCH} \quad (1)$$

where: AFT55 = Length of overlay life-cycle corresponding to PCR level of 55 years
BEF55 = Length of initial pavement structure life-cycle corresponding to PCR level of 55, years
THOV = Thickness of overlay, mm
ESAL = Number of equivalent single axle loads per day calculated using Equation 2

$$ESAL = (AADT83 \cdot TRUCK \cdot TRUCKF \cdot LDF)/ 200 \quad (2)$$

where: AADT83 = 1983 Annual Average Daily Traffic
TRUCK = Truck percentage
TRUCKF = Truck factor
LDF = Lane Factor

PATCH = An indicator (dummy) variable to account for presence of patching during the initial cycle. The indicator variable was used to introduce into the regression analyses patching information which was measured on a nominal (non-numerical) scale [8]. PATCH was set to 0 for no or a limited amount of patching and to 1 for all other cases.

The selected model was not the one with the best statistical parameters, but the best one considering both statistical parameters and rational model formulation. The model doesn't contain any interactive terms, even though some interaction between the model variables probably occurs. The number of observation sections was insufficient to include any interactive terms.

3.2.2/ Model Evaluation

Statistical parameters of the model represented by Equation 1 are summarized in Table 1. The model was highly statistically significant with R-square [9] of 0.72. This means that 72% of the total variance was explained by the model. The model's root mean square error, an estimate of the standard deviation of the error term, was 1.12 years. All partial regression coefficients of the independent variables were statistically significant; the intercept was not statistically significant (Table 1).

Table 1 also shows values and statistical significance of correlation coefficients for variables of Equation 1. There was only a limited amount of intercorrelation between the model variables. The overlay thickness, while exhibiting no significant correlation with PCR jump ($R = -0.11$) or with PCR before resurfacing ($R = 0.19$), had somewhat significant correlation with RCR ($R = 0.24$). This indicates that overlays tended to be thicker when the Riding Comfort Rating of the initial pavement was lower.

A plot of measured versus calculated values is shown in Figure 3. The residuals, differences between the predicted and observed AFT55 values, were normally distributed.

The prediction model defined by Equation 1 can be advantageously used to isolate and quantify the effects of the model variables. The effect of individual variables and evaluation of rational behaviour of the model, in view of the factors known to influence the overlay performance, are discussed in the following.

a) Overlay Thickness

The overlay thickness was the only variable used to characterize the overlay strength. No distinction was made between recycled or virgin mixes. All overlays were placed over existing asphalt concrete pavements.

Equation 1 can be rearranged to predict overlay thickness for a desired length of overlay life-cycle:

$$THOV = \left(\frac{AFT55}{1.32 \cdot BEF55^{0.33} \cdot ESAL^{-0.097} \cdot 1.14^{PATCH}} \right)^{2.13} \qquad (3)$$

The relationship between overlay thickness and overlay life is illustrated in Figures 4a and 4b. Both figures assume that the initial pavement life-cycle was 13 years (data set average). Furthermore, Figure 4a assumes that none or only a small amount of maintenance patching was done in the first cycle; Figure 4b assumes that more extensive patching was done. For a typical range of overlay thickness, the doubling of thickness results in a five year increase in overlay life. However, the relationship between overlay thickness and overlay life is not linear.

Figures 4a and 4b also show a corresponding relationship obtained using OPAC prediction method [6] based on average data set values and a subgrade layer coefficient, M_S, equal to 5000. The model results and the OPAC results are quite similar, particularly for the case with the maintenance patching. Without the maintenance patching, the OPAC method overestimates overlay life by about three years. The tendency of OPAC to overestimate pavement performance has been noticed before [1].

The compatibility of the two prediction methods may be attributed, to some extent, to coincidental selection of "average" OPAC input data. However, it is interesting to note that the shapes of curves relating overlay thickness to overlay life are very similar. It also should be stressed that the empirical model of Equation 1 requires only readily available data while the mechanistically based OPAC prediction method requires considerably more detailed data which is not always available.

Figures 4a and 4b can be used for rough estimation of overlay thickness requirements. An example is shown in Figure 4a. For a desired overlay life of 15 years and assuming:

- no significant amount of patching,
- initial pavement life of 13 years, and
- 100 ESAL per day (approx. AADT of 3 000 with 14% of trucks),

the recommended overlay thickness is 70 mm.

b) Patching

According to Figure 5, the presence of patching during the initial pavement cycle increased the overlay life by about two years. It appears that patching, usually done near the end of the initial pavement cycle, strengthened the pavement structure where such strengthening was most required. The overlay performance benefited from this action, assuming that patches were overlayed before they deteriorated.

Patching during the initial pavement cycle occurred about 15 or 20 years ago and data describing patching extent and timing lack many details. Nevertheless, even in this crude form, the effect of patching was statistically significant (Table 1).

Equation 1 represents a pavement damage equation which includes the effect of maintenance. Historically, pavement damage functions have been unable to include and quantify the effect of maintenance [10, 11]. Equation 1 does this in a format fully compatible with the requirements of life-cycle economic analyses.

The effect of maintenance patching in the second (overlay) cycle was also evaluated but could not be quantified. There were also problems with data. Patching is usually done at the end of the pavement life. Thus, the effect of the second cycle patching may not be fully accounted for if the serviceability limit is set at PCR equal to 55 and/or if the patching has not been done yet. In such cases, the length of the second life-cycle was extrapolated from historical trends.

c) Traffic

The traffic exposure was characterized by the number of equivalent single axles in 1983 (Equation 2). This characteristic was selected because it correlated better with the length of overlay life-cycle (AFT55) than overall (AADT) volumes.

The relationship between traffic and AFT55, illustrated in Figure 6, is expressed both in terms of ESAL and AADT volumes. AADT volume is assumed to contain 14% of trucks and to have a typical truck factor.

d) Length of Initial Pavement Structure Life-Cycle

Variables related to the strength of the pavement being overlayed (such as thickness of asphalt concrete), and variables characterizing environmental exposure (such as the freezing index) were expected to be useful in predicting the overlay life. However, none of these variables exhibited any predictive potential with the exception of the length of the initial pavement life-cycle.

For 16 observations, the initial pavement cycle was a new construction or reconstruction; in four cases the initial pavement cycle was an overlay. The average initial pavement life-cycle was 13.1 years; the average subsequent (overlay) life-cycle was 14.8 years.

Figure 7 illustrates the observed relationship between the length of the initial pavement life-cycle and the subsequent overlay cycle, both cycles being referenced to the same minimum performance level of PCR equal to 55. The effect of the initial cycle length is quite pronounced; on average, all other variables being equal, a five year increase in the initial pavement life resulted in a two year increase in the overlay life.

The life span of the initial pavement structure embodies site-specific, long-term interaction between the pavement structure, including maintenance, and traffic and environmental exposures. If, for example, the initial pavement structure performs poorly, perhaps because of local soil or drainage conditions or unusually heavy traffic loads, chances are that the overlay performance will also be negatively influenced by the same conditions. The length of the initial pavement life-cycle is thus a very comprehensive, site-specific and readily available predictor of overlay performance which should not be overlooked even by mechanistically-based overlay design methods.

3.2.3/ Model Verification

Because of the relatively small number of observations available for the model development (20), and because of the method used for their selection (Section 2.1), an additional six observations were selected in a random manner to evaluate independently the model accuracy.

The results of this evaluation, presented in Table 2, indicate that the model's accuracy is roughly in line with expectations. The standard deviation of the difference between measured and predicted AFT55 values for the six additional observations was 2.07 years, which compares favourably with the model's root mean square error of 1.12 years.

3.3/ PCR Change During 5 Years After Overlay

The prediction of PCR change during the first five years of overlay life (ΔPCR5) complements the prediction of overlay life-cycle length and was motivated by two reasons.

a) Data availability

The development of the overlay life-cycle prediction model required pavement performance data, for the same basic pavement structure, spanning two pavement life-cycles (or approximately covering 25 to 40 years). Because the ΔPCR5 prediction modelling required considerably less historical data, an additional 30 observations were available for a total of 50 observations. Also, it was hoped that the ΔPCR5 prediction could serve as a surrogate of the total life-cycle prediction.

b) Performance curve

Prediction of ΔPCR5 helps to define the shape of the pavement performance curve. The shape of the performance curve, in addition to its length, is often used in economic analyses.

3.3.1/ Model Description

A considerable number of ΔPCR prediction models were constructed and evaluated. These models related ΔPCR with variables characterizing pavement structure and pavement condition before overlay, as well as overlay itself. The following prediction model was selected because of its rational structure, statistical parameters and simplicity.

$$\Delta PCR5 = 36.31 \cdot THOV^{-0.65} \cdot ESAL^{0.16} \cdot DM^{0.21} \qquad (4)$$

where: ΔPCR5 = Change in PCR during 5 years following overlay placement, PCR units.
THOV and ESAL were defined for Equation 1, and
DM (distress manifestations) was defined in Section 2.2(e).

Statistical parameters of the model represented by Equation 4 are summarized in Table 3. Even though the multiple correlation coefficient of the model was relatively low (R^2 = 0.26), the model itself and its partial regression coefficients were statistically significant. There was no intercorrelation between model variables (Table 3). The correlation coefficient between ΔPCR5 and the length of overlay life-cycle (AFT55) was -0.47 indicating that ΔPCR5 can serve as a surrogate for AFT55.

The prediction of ΔPCR5 suffered more from the subjectiveness of the PCR scale than the prediction of the overlay life (AFT55). The change in ΔPCR5 starts at the top of the PCR scale which may be also influenced by the halo effect described in Section 3.1.

Equation 4 is graphically represented in Figures 8a and 8b. Figure 8a illustrates the influence of overlay thickness on ΔPCR5. Figure 8b shows that the index of pavement distress manifestations at the time of overlay placement (DM) influences the rate at which the overlay deteriorates, ΔPCR5, at least in the first five years of its life. Equation 4 thus quantifies, on a statistical basis, the effects of deferring overlays: A postponement of overlay placement increases DM, the increase in DM accelerates pavement deterioration (ΔPCR5). Alligator cracking (ALLIG in Section 2.2) had a similar influence on ΔPCR5 and was also highly correlated with DM (Table 2).

Figure 8b also indicates that the drop in PCR (ΔPCR5) is lower for thicker overlays. The relationship is not linear. The improvement due to the increase from 60 to 120 mm was quite small.

4/ CONCLUSIONS AND RECOMMENDATIONS

1. Long-term pavement performance data can be used to develop reliable empirical models for performance prediction of various rehabilitation treatments. These models can include the effect of maintenance effort and can be used for life-cycle economic analyses.

2. As an example, a damage model (i.e., an equation predicting pavement condition) has been developed for asphalt concrete overlays over existing asphalt concrete pavements. The model predicts the length of the overlay life-cycle, for a predetermined terminal serviceability, as a function of overlay thickness, traffic, maintenance patching, and the life-cycle length of the initial pavement. The last variable, included in the model to characterize the interaction between the initial pavement structure and its traffic and environmental exposures, appears to be a very useful, readily available and site-specific variable.

3. The model developed for prediction of the drop in pavement serviceability during five years following the overlay placement (ΔPCR5) quantifies the influence of pavement distress conditions before overlay placement on the overlay performance.

4. The proposed overlay performance prediction models and their coefficients were statistically significant despite many simplifications and possible sources of error (e.g., variability due to section length and difficulties in quantifying maintenance effort).

5. Pavement performance prediction, and indeed the whole issue of life-cycle costing, could benefit from a more objective measure of pavement serviceability than that provided by Pavement Condition Rating (PCR).

6. The present study should be viewed as a pilot study. The proposed models should be updated when more data become available both to increase the models' data base and as an ongoing adjustment to reflect overlay design changes. Additional models should be developed for other rehabilitation treatments.

7. The prediction used in this study relies on statistically documented experience. The gathering of this experience would be greatly enhanced by the results of an ongoing study on Continual Observation of Pavement Performance (COPP) [12].

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Table 1/ Statistical Parameters of AFT55 Prediction Model

Analysis of Variance Table

Source of Variance	Degree of Freedom	Sum of Squares	Mean Square	F Value	Level of Significance
Regression Model	4	0.0919	0.0230	9.84	0.04%
Error	15	0.0350	0.0023	-	-
Corrected Total	19	0.1270	-	-	-

Table of Partial Regression Coefficients

Parameter	Estimate	Std. Error of Estimate	Student's t for HO:Para = 0	Level of Significance
Intercept	0.121	0.264	0.46	65.0%
log THOV	0.472	0.140	3.37	0.4%
log ESAL83	-0.097	0.026	-3.74	0.2%
log BEF55	0.331	0.098	3.38	0.4%
PATCH	0.058	0.022	2.62	1.9%

Table of Correlation Coefficients

	THOV	ESAL83	BEF55	PATCH	AFT55
THOV	1.00				
ESAL83	0.25	1.00			
BEF55	0.03	0.05	1.00		
PATCH	-0.14	-0.01	0.16	1.00	
AFT55	0.41	-0.41	0.45	0.35	1.00

Note 1: All correlation coefficients are based on 46 to 50 observations with the exception of correlation coefficients involving AFT55 which are based on 20 observations.

Note 2: Correlation coefficients based on 50 observations are significant at 10% level of significance if their value exceeds 0.24. The corresponding value for correlation coefficients based on 20 observations is 0.36.

Table 2/ Model Verification

Obs. No.[1]	Initial Cycle Life BEF55 (years)	Overlay Thickness THOV (mm)	Traffic loads ESAL (axles)	Maintenance Patching PATCH (0 or 1)	Overlay life, AFT55		Difference Observed - Predicted (years)
					Observed (years)	Predicted[2] (years)	
1	16	55	102	1	18	16.0	2.0
2	8	60	37	1	16[3]	14.6	1.4
3	6[4]	60	15	1	11	14.5	-3.5
4	11	50	177	0	12	11.2	0.8
5	16	60	77	0	17[3]	15.0	2.0
6	13	40	50	1	14	13.8	0.2
						average	0.48
						std. deviation	2.07

Notes: 1) Listed as observation sections 51 through 56 in Appendix A
2) Using Equation 1
3) Extrapolated for next 5 years
4) Pavement structure before overlay included 100 mm of cold mix

Table 3/ Statistical Parameters of ΔPCR5 Model

Analyses of Variance Table

Source of Variance	Degree of Freedom	Sum of Squares	Mean Square	F Value	Level of Significance
Regression Model	3	0.398	1.33	5.08	0.4%
Error	42	1.098	0.026		
Corrected Total	45	1.496			

Table of Partial Regression Coefficients

Parameter	Estimate	Standard Error of Estimate	Student's t for HO: Para = 0	Level of Significance
Intercept	1.555	0.367	4.24	0.1%
log THOV	-0.655	0.208	-3.15	0.3%
log ESAL83	0.161	0.060	2.68	1.0%
log DM	0.211	0.116	1.82	7.6%

Table of Correlation Coefficients

	THOV	ESAL83	DM	ΔPCR5	ALLIG	RCR
THOV	1.00					
ESAL83	0.25	1.00				
DM	0.27	0.15	1.00			
ΔPCR5	-0.28	0.12	0.19	1.00		
ALLIG	-0.16	-0.07	0.54	0.30	1.00	
RCR	0.24	0.13	0.13	-0.08	-0.03	1.00

Note 1: Correlation coefficients are based on 46 to 50 observation sections.

Note 2: Statistical significance of correlation coefficients is outlined in Note 2, Table 1.

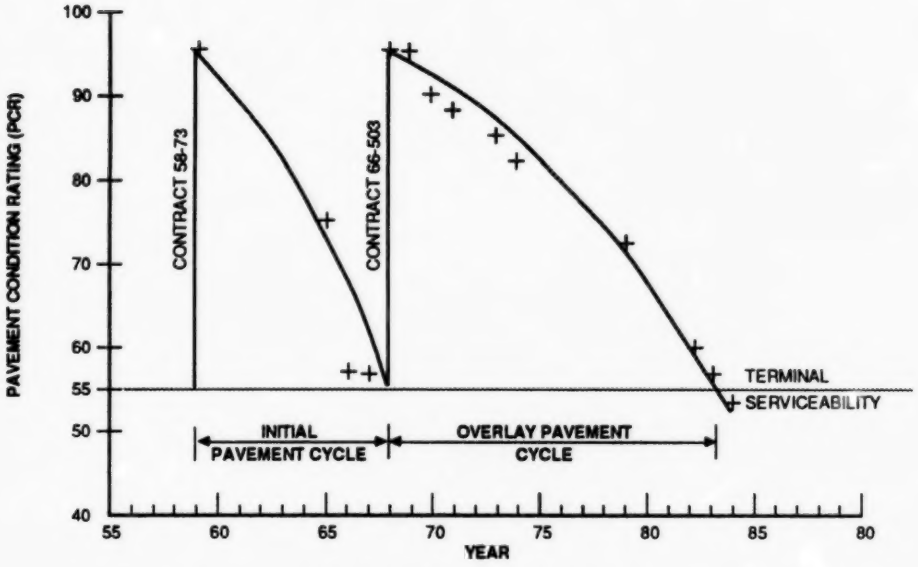

Figure 1/ Pavement Life-Cycles (For Observation 6 in Appendix A)

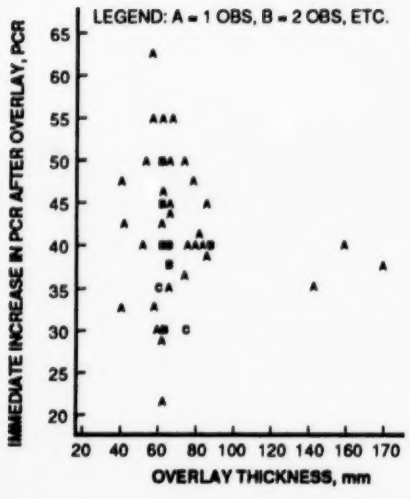

Figure 2/ Relationship Between Increase in PCR and Overlay Thickness

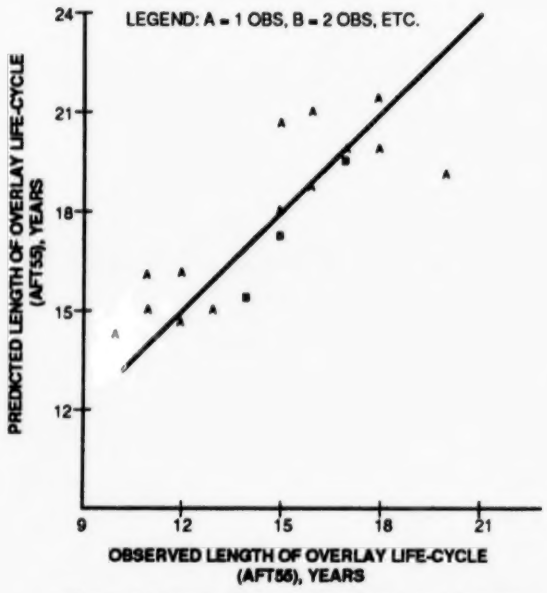

Figure 3/ Comparison of Observed and Predicted Length of Overlay Life-Cycle (AFT55)

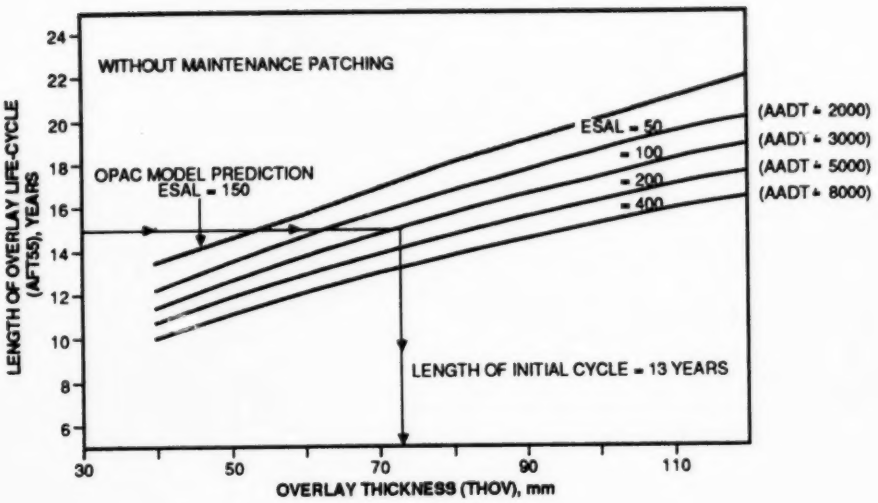

Figure 4(a)/ Effect of Overlay Thickness on Overlay Life, No Maintenance Patching

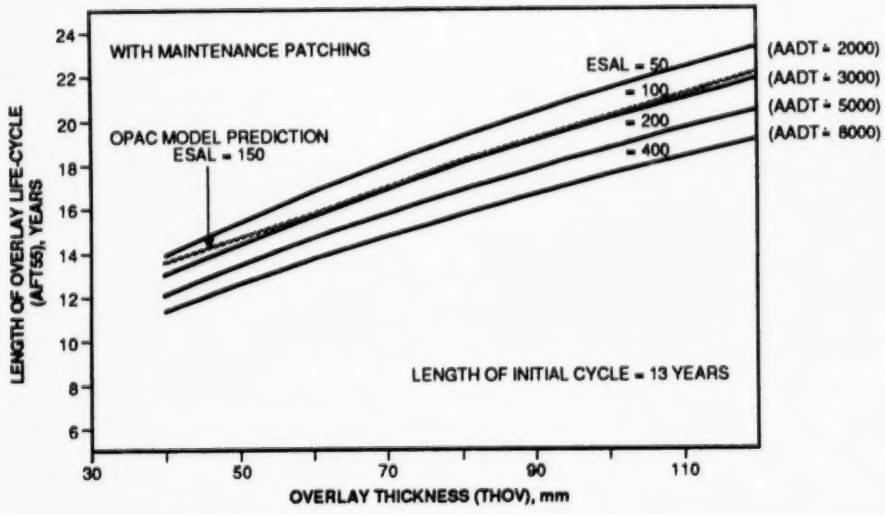

Figure 4(b)/ Effect of Overlay Thickness on Overlay Life, With Maintenance Patching

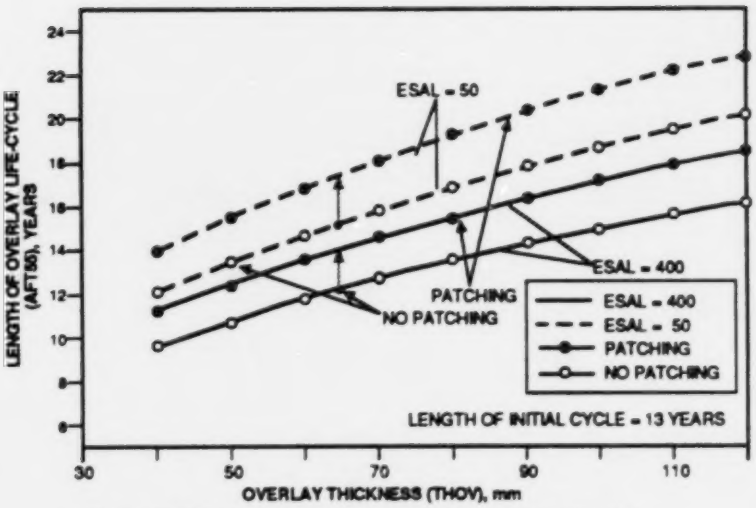

Figure 5/ Effect of Maintenance Patching on Overlay Life

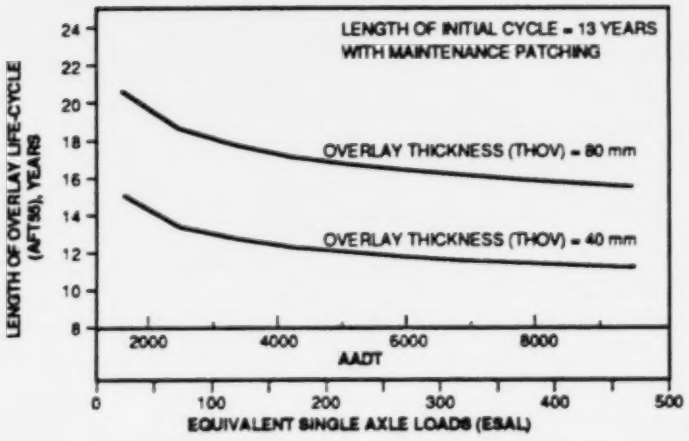

Figure 6/ Effect of Traffic on Overlay Life

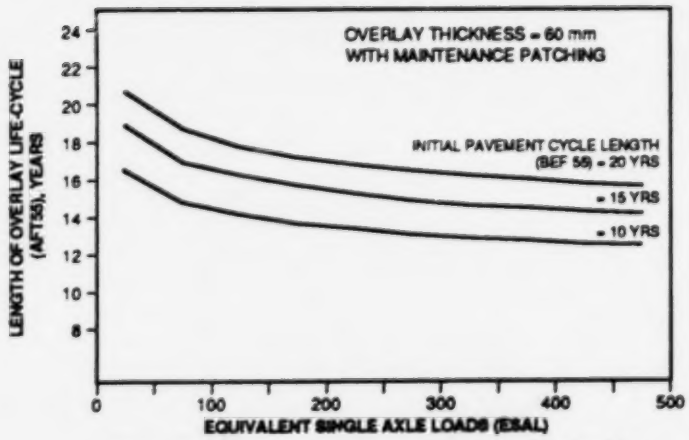

Figure 7/ Effect of Initial Pavement Life on Overlay Life

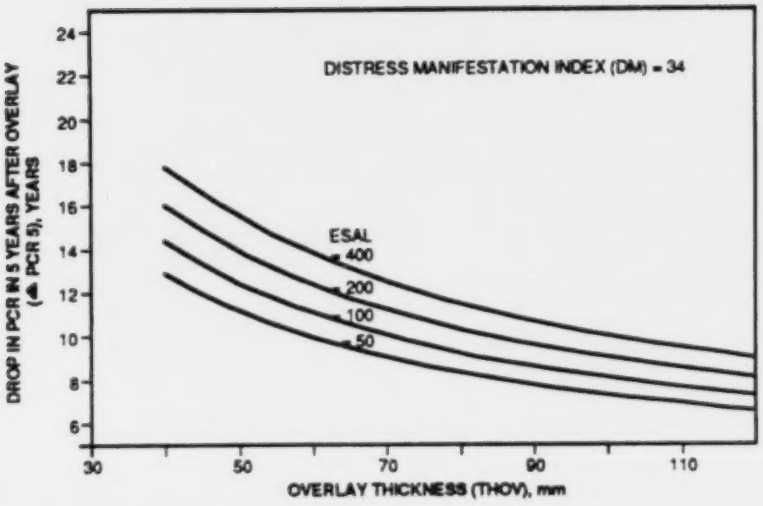

Figure 8(a)/ Effect of Overlay Thickness on PCR Drop

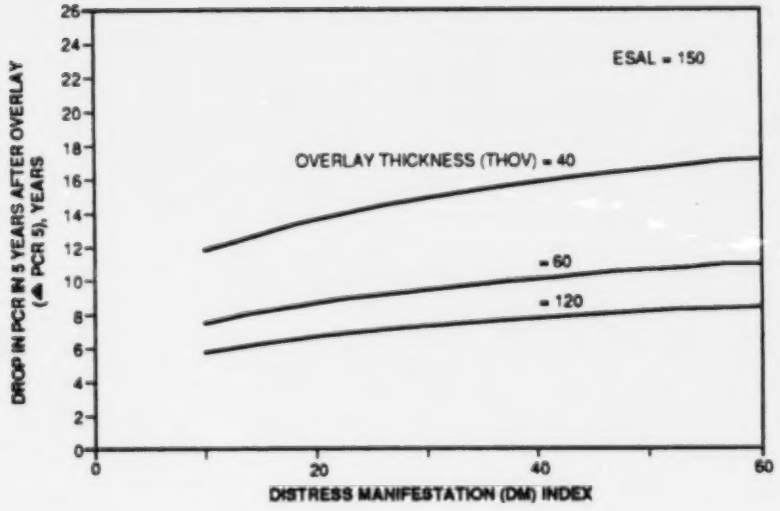

Figure 8(b)/ Effect of Distress Manifestation Index on PCR Drop

APPENDIX A

Variables listed in Table A1 in the Appendix have been grouped into seven categories and are defined below.

a) Section Identification Variables

OBS	Observation number
DIST	MTC District number
HWY	Highway number
LHRS	LHRS number (number indicating section location)
OFFSET	Offset number (number indicating section location within LHRS)
LENGTH	Section length in km

b) Traffic Characteristics

AADT63	Annual Average Daily Traffic volume (AADT) in 1963
AADT83	Average AADT volume in 1983
AVGDT	AADT volume during the initial pavement cycle (Figure 1)
GRA2	AADT growth rate between 1973 and 1983
TRUCK	Percentage of trucks in 1983
TRUCKF	Truck factor
ESAL83	Number of equivalent single axle loads in 1983

c) Environmental Characteristics

FREEZE	Freezing Index, degree days Celsius.

d) Initial Pavement Structure and Its Maintenance

BEFAC	Total thickness of asphalt concrete, mm
GRANA	Equivalent thickness of granular base course (Granular A) material, mm
PATCH	Extent of maintenance patching during the initial cycle, 0 = none or some, 1 = more extensive patching

e) Pavement Performance During the Initial Cycle

BEFCON	Pavement Condition Rating (PCR) value at the beginning of the initial cycle
BEF55	Number of years before the initial pavement structure reached PCR = 55
PCRJ	Estimated PCR immediately prior to the overlay cycle
LPCR5	Change in PCR over last 5 years before the overlay

RCR	Ride Comfort Rating just before overlay
ALLIG	Total alligator cracking index just before overlay
DM	Total Distress Manifestations Index just before overlay

f) Overlay Structure and Its Maintenance

AGE	Age of pavement when overlay was placed, years
AFTCON	Year of overlay placement
AFTAC	Total thickness of asphalt concrete, mm
THOV	Total overlay thickness, mm
IND	Indicators of overlay type, 0 = no milling, 1 = milling
PATCH2	Extent of maintenance patching during the overlay cycle, 0 = none or some, 1 = more extensive patching

g) Overlay Performance

AFT55	Number of years before overlay reached PCR = 55
ΔPCR3	Change in PCR during the first three years following overlay placement
ΔPCR5	Change in PCR during the first five years following overlay placement

Table A1/ Data for the Prediction of Pavement Performance

OBS	DIST	HWY	LHRS	OFFSET	LENGTH	AADT63	AADT83	AVGDT	GRA2	TRUCK	TRUCKF	ESAL83	FREEZE	BEFAC	GRAN	PATCH	BEFCON	BEF55	PCRJ	LPCR5	RCR	ALIG	DM	AGE	AFTCON	AFTAC	THOV	IND	PATCH2	AFT55	ΔPCR35	ΔPCR55
1	1	79	14740	0.2	7.3	850	1100	986	1.00	24.0	0.35	46	450	50	400	0	95	12	60	13	5.0	2.0	20.5	11	74	110	60	0	0	15	0	6
2	2	3	11830	0.3	9.1	4600	3850	4611	0.86	16.0	0.60	185	420	125	225	1	92	16	60	.	5.0	9.5	21.0	14	74	165	40	0	1	12	7	19
3	2	19	23450	1.3	10.5	3200	4800	3200	1.00	12.0	0.60	173	450	110	400	1	95	10	45	10	4.0	13.5	49.7	15	70	160	50	0	1	14	7	13
4	2	81	37600	0.0	7.4	2300	3500	2660	1.00	22.0	0.50	193	450	75	200	0	95	12	40	30	5.0	19.0	33.5	14	73	135	60	0	1	14	12	18
5	3	7	14520	5.6	8.0	4600	7000	4600	1.27	17.0	0.75	446	600	125	300	1	95	20	53	17	5.0	12.5	47.5	21	73	185	60	0	.	.	2	10
6	3	7	14620	0.0	6.3	4000	8000	4000	1.33	12.0	0.75	360	600	115	350	1	95	9	55	30	5.0	6.0	23.0	9	66	200	85	0	0	15	7	10
7	3	19	23530	2.1	24.0	1300	2150	1438	1.16	16.0	0.45	77	650	100	150	1	95	10	48	19	5.0	19.0	42.5	13	72	140	40	0	1	13	10	18
8	8	2	10550	13.1	18.2	2600	3100	2624	1.00	6.0	0.50	47	700	110	350	1	95	12	40	0	4.0	12.0	29.5	21	74	167	57	0	.	.	4	8
9	8	7	14090	0.0	13.2	2400	3800	2400	1.00	19.0	0.60	217	870	115	300	1	95	16	55	.	5.0	9.0	27.5	17	69	185	70	0	0	17	4	10
10	8	7	14100	0.0	13.0	2400	3700	2400	1.04	19.0	0.60	211	860	90	300	1	85	15	55	.	5.0	12.0	35.5	15	69	160	70	0	0	17	0	0
11	8	7	14110	0.0	10.0	2000	3700	2641	1.04	19.0	0.60	211	850	110	300	1	95	20	60	7	5.0	0.0	48.0	19	77	175	65	0	.	.	6	13
12	8	7	14110	10.0	15.8	2000	3100	2451	1.11	19.0	0.50	147	840	115	350	1	95	20	65	9	5.0	0.0	41.0	16	77	180	65	0	.	.	7	13
13	8	7	14130	12.0	13.9	1900	3100	2619	1.05	19.0	0.50	147	820	115	350	0	95	18	55	20	5.0	1.5	47.0	18	80	190	155	1	.	.	3	5
14	8	7	14150	12.7	12.7	2100	4000	3519	1.00	19.0	0.60	228	800	190	300	1	95	17	57	10	6.0	5.5	69.0	16	80	285	175	1	.	.	4	8
15	8	7	14170	0.0	8.6	2100	4000	2100	1.00	12.0	0.60	144	800	105	375	0	95	20	59	3	5.0	0.0	12.0	17	70	175	70	0	1	20	5	8
16	8	15	20030	7.0	12.3	1800	3400	2344	1.17	9.5	0.50	81	800	90	225	0	95	14	54	10	5.5	0.0	24.5	14	75	170	80	0	.	.	3	7
17	8	15	20060	2.7	20.0	1600	3300	1670	1.10	9.0	0.50	74	820	85	350	0	95	12	48	16	5.0	0.0	38.5	15	71	160	75	0	0	15	5	10
18	8	15	20070	9.0	10.0	2300	4700	2300	1.07	9.5	0.60	134	870	125	350	1	95	15	45	0	4.0	0.0	11.5	23	70	195	70	0	1	17	5	15
19	8	33	27400	3.0	9.4	700	1000	832	1.10	9.0	0.35	16	500	50	300	0	95	14	60	21	5.0	5.5	41.0	13	76	110	60	0	.	.	4	8
20	8	62	33740	0.0	15.5	950	1750	1142	1.00	9.0	0.45	35	800	100	200	0	95	17	45	20	5.0	12.0	40.5	19	75	160	60	0	.	.	11	17
21	9	2	10300	0.0	10.2	2100	1800	2065	1.00	5.0	0.45	20	900	75	250	1	95	.	32	5	4.0	14.0	35.0	25	77	130	55	0	.	.	1	4
22	9	2	10320	6.1	5.0	3200	5400	3886	1.00	5.0	0.60	81	870	120	350	1	95	18	50	12	5.0	0.0	24.5	21	77	150	60	0	.	.	2	5
23	9	2	10330	3.2	7.5	2000	3200	2102	1.45	5.0	0.50	40	860	120	350	0	95	17	50	9	5.0	0.0	20.3	20	77	180	60	0	.	.	2	7
24	9	2	10340	0.0	16.0	2000	2000	2000	1.00	5.0	0.45	23	800	110	250	0	95	19	45	25	6.0	5.0	44.3	22	79	175	65	0	.	.	5	10
25	9	2	10360	0.0	10.3	1600	1900	1740	0.95	8.0	0.45	34	770	95	250	1	95	20	55	8	5.0	12.0	28.5	20	77	155	60	0	.	.	2	5
26	9	7	14026	0.0	10.6	3600	8000	6872	1.07	12.0	0.75	360	960	200	225	0	95	16	55	24	5.0	11.5	56.8	17	82	280	80	0	.	.	1	.
27	9	7	14030	3.7	8.5	3400	8000	6467	1.00	9.5	0.75	285	950	190	225	0	95	19	65	5	6.0	6.0	29.5	15	78	255	65	0	.	.	6	12
28	9	7	14050	0.0	11.5	2000	5000	3232	1.09	15.0	0.60	225	960	95	350	0	95	14	50	14	5.5	5.0	29.3	16	76	160	65	0	.	.	6	13
29	9	15	26610	10.0	14.6	2000	3200	2699	1.14	11.0	0.50	88	880	125	225	0	90	13	45	20	4.0	25.5	64.3	15	80	125	.	1	.	.	17	20
30	9	17	20560	6.3	18.8	2000	8000	2000	0.71	6.0	0.75	180	1010	.	.	1	95	20	57	11	6.0	0.0	8.5	19	70		65	0	0	15	8	12

Table A1/ Data for the Prediction of Pavement Performance (con't)

OBS	DIST	HWY	LHRS	OFFSET	LENGTH	AADT63	AADT83	AVGDT	GRA2	TRUCK	TRUCKF	ESAL83	FREEZE	BEFAC	GRANA	PATCH	BEFCON	BEF55	PCRJ	LPCR5	RCR	ALLIG	DM	AGE	AFTCON	AFTAC	THOV	IND	PATCH2	AFT55	ΔPCR3	ΔPCR5
31	9	17	20650	0.0	15.4	3000	7300	4774	1.49	9.0	0.75	246	1010	120	350	0	95	14	55	18	6.0	0.0	58.0	14	79	185	65	0	.	.	8	8
32	9	17	20660	0.0	10.6	3000	6600	5009	1.25	13.0	0.75	322	1020	120	350	0	95	16	57	17	6.0	26.3	57.5	15	80	185	65	0	.	.	8	12
33	9	17	20730	4.0	13.0	2000	4400	2863	1.16	17.0	0.60	224	1060	75	350	0	90	15	60	15	5.0	0.0	24.0	16	76	135	60	0	0	11	11	14
34	9	31	27000	0.0	10.0	2100	3600	4338	0.78	16.0	0.60	173	820	75	.	0	95	7	56	14	4.0	17.0	20.5	7	77	160	85	0	.	.	1	5
35	9	31	27010	7.0	13.2	2500	3000	2855	1.00	17.0	0.50	128	860	75	.	0	95	12	55	10	4.0	0.0	24.0	12	78	160	85	0	.	.	2	8
36	9	31	27040	0.0	10.2	2200	3700	5869	0.56	13.0	0.60	144	900	75	.	0	95	8	50	10	4.0	5.0	28.8	8	78	160	85	0	.	.	3	8
37	9	34	27600	0.0	19.4	1700	2600	1700	0.96	12.0	0.50	78	940	85	.	0	95	24	55	.	5.5	0.0	8.5	24	73	150	65	0	.	.	3	5
38	9	43	30070	0.0	11.8	1100	1400	1355	1.00	18.0	0.45	57	880	55	250	0	95	12	55	10	6.0	25.5	43.5	12	79	130	75	0	.	.	5	15
39	9	44	30300	0.0	13.8	1000	2900	1887	1.45	8.0	0.50	58	890	75	185	0	95	.	66	9	7.0	15.5	47.5	.	79	135	60	0	.	.	5	8
40	9	60	33200	0.0	12.4	450	1200	1078	1.00	10.0	0.35	21	1050	90	350	0	95	13	55	15	5.0	27.0	75.5	13	81	140	50	0	.	.	.	.
41	9	60	33220	0.8	13.3	900	1600	1119	1.07	20.0	0.45	72	1060	50	125	1	95	17	48	17	5.0	4.0	11.5	17	77	90	40	0	.	.	5	8
42	10	41	29600	7.9	12.6	500	1200	601	1.33	12.0	0.35	25	1000	50	350	1	88	11	53	5	5.0	2.0	18.5	11	70	110	60	0	0	18	8	13
43	10	62	33810	1.4	13.6	1800	3000	1737	1.00	8.0	0.50	60	1050	50	300	1	86	.	65	0	6.0	0.0	21.5	.	74	110	60	0	.	.	3	6
44	11	11	17090	2.9	22.7	2800	6500	2800	1.41	16.0	0.75	390	970	60	510	0	95	10	40	25	4.5	0.0	30.0	10	70	125	65	0	0	10	5	15
45	11	60	33310	8.4	23.6	800	1000	980	0.80	4.0	0.35	7	1100	50	225	1	84	8	40	25	4.5	12.0	31.0	8	72	115	65	0	1	16	4	7
46	11	69	35380	0.0	19.1	3000	6500	5008	1.27	11.0	0.75	268	850	130	225	0	95	13	60	12	7.0	6.0	39.5	13	79	170	140	1	.	.	0	10
47	14	11	17360	4.4	20.3	1700	2400	1991	1.09	20.0	0.50	120	1780	110	500	0	95	9	49	9	3.0	5.0	40.5	9	76	170	60	0	1	11	7	13
48	14	112	41900	0.0	19.8	1200	1300	1210	1.00	9.0	0.35	20	1800	100	400	0	95	13	45	22	5.0	22.5	40.5	13	72	160	60	0	1	16	10	20
49	16	11	17760	18.5	15.8	750	1350	752	1.80	24.0	0.35	57	2040	110	300	1	95	18	55	11	5.0	0.0	18.5	18	74	170	60	0	0	18	8	12
50	17	69	35530	2.9	26.7	2700	4100	2700	1.00	14.0	0.60	172	1200	100	350	0	88	11	55	7	5.0	0.0	29.5	11	69	155	55	0	1	12	8	18
51	5	26	25680	5.8	9.9	.	4000	.	.	8.5	0.60	102	.	.	.	1	.	16	.	.	.	.	.	16	.	.	55	.	0	18	.	.
52	17	6	13890	3.0	23.0	.	2200	.	.	6.7	0.50	37	.	.	.	1	.	8	.	.	.	.	.	8	.	.	60	.	1	16	.	.
53	2	59	32920	0.0	9.7	.	1400	.	.	5.5	0.40	15	.	.	.	1	.	6	.	.	.	.	.	6	.	.	60	.	0	11	.	.
54	17	69	35560	0.0	1.9	.	4800	.	.	12.3	0.60	177	.	.	.	0	.	11	.	.	.	.	.	11	.	.	50	.	0	12	.	.
55	5	4	12910	6.8	9.9	.	1700	.	.	18.0	0.50	77	.	.	.	0	.	16	.	.	.	.	.	16	.	.	60	.	0	17	.	.
56	1	7	14790	4.2	8.0	.	3000	.	.	6.5	0.50	49	.	.	.	1	.	13	.	.	.	.	.	13	.	.	40	.	1	14	.	.